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NEOPHOBIA: SOCIO-ETHICAL PROBLEMS OF INNOVATIVE TECHNOLOGIES OF THE FOOD INDUSTRY

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food systems, innovative technologies, neophobia, nanotechnologies, genetic modification, 3D printing, safety, risks

ABSTRACT
The purpose of this review work is to consider the impact of socio-ethical problems on the acceptance of new food products by potential consumers and the issues of manufacturers of these products when introducing innovative technologies. The causes of neophobia of innovative technologies in the food industry are considered on specific examples of the use of nanotechnology, genetic modification technologies, ionization and processing by electromagnetic fields, as well as 3D food printing. It is noted that the public is little aware of innovative food technologies, while its attitude depends on how these technologies are used and promoted. Proper public information is critical to the long-term success of introducing and developing innovative technologies in the food industry. It is shown that the modern intensive development of information technologies, together with a synergistic set of innovative food technologies, allows making a gradual transition to the production of personalized digital food systems that have functionality, good taste, and safety with minimal negative impact on the environment.

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НЕОФОБИЯ: СОЦИАЛЬНО-ЭТИЧЕСКИЕ ПРОБЛЕМЫ ИННОВАЦИОННЫХ ТЕХНОЛОГИЙ ПИЩЕВОЙ ПРОМЫШЛЕННОСТИ

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КЛЮЧЕВЫЕ СЛОВА:
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АННОТАЦИЯ
Цель этой обзорной работы состоит в рассмотрении влияния социально-этических проблем на принятие потенциальными потребителями новых пищевых продуктов и проблем производителей этих продуктов при внедрении инновационных технологий. Рассмотрены причины возникновения неофобий инновационных технологий пищевой промышленности на конкретных примерах использования нанотехнологий, технологий генной модификации, обработки ионизирующим излучением и электромагнитными полями, а также пищевой 3D-печати. Отмечено, что общественность, мало осведомлена об инновационных пищевых технологиях, в то время как её отношение зависит от того, как эти технологии используются и пропагандируются. Надлежащее информирование общества имеет решающее значение для долгосрочного успеха внедрения и развития инновационных технологий в пищевой промышленности. Показано что современное интенсивное развитие информационных технологий совместно с синергетической совокупностью инновационных пищевых технологий, позволяет совершить постепенный переход к производству персонализированных цифровых пищевых систем, обладающих функциональностью, хорошим вкусом, безопасностью при минимальном отрицательном воздействии на окружающую среду.

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1. Introduction

The development and commercial use of innovative technologies in industry always encounters various kinds of problems and is constantly accompanied by them. There are objective problems: technical, technological, economic, etc., but there are also subjective problems — socio-ethical, and neophobia, first of all, belongs to them.

Neophobia, by definition, is the fear of everything new, unusual. This feeling, sometimes developing into a problem, is inherent in any person to some extent. The consumer, having seen a new product, doubts its safety, quality and the need to purchase, and this creates problems for the manufacturer, who needs a good sale of the product. In turn, the manufacturer of a new product or when switching to a new production technology also develops neophobia at a certain stage, due to the uncertainty of the success of mastering a new technology or marketing a new product.

New food technologies are essential for food security and sustainable development. However, manufacturers and consum-

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ers are often hesitant to accept them. Review paper [1] describes how heuristics and individual differences among consumers affect the adoption of agrifood technologies. The associations evoked by food technology, its perceived naturalness, and the credibility of the industry using it affect consumer acceptance. Food neophobia, disgust sensitivity, and cultural values are crucial personality factors to explain individual differences. Using gene technologies, nanotechnology, cultured meat, and food irradiation as examples, the authors explore factors that may explain consumer acceptance or rejection of these technologies.

The food neophobia also influence the commercialization of innovative food technologies. People differ in the degree of their food neophobia — this is an unwillingness to try and consume new foods [2]. Some people take great pleasure in eating new foods, while others show a strong aversion to them. Food neophobia is considered a kind of defense mechanism to prevent the consumption of potentially hazardous foods [3] because the toxicological nature of the hazard, the probability of impact, and the risk to consumers from some new food technologies are largely unknown.

For consumers, food production is increasingly becoming a black box. The prevalence of highly processed foods and declining cooking skills further alienate many consumers from how food is produced and how meals are prepared. If a technology is seen as unnatural, terrible, and uncontrollable, and if people don't voluntarily become familiar with it, its acceptance tends to be low. Factors associated with a particular personality further influence the perception of technology. However, the factors that are most important for food unacceptability vary depending on the food technology used. In many developed countries, natural food is highly valued because food safety is considered guaranteed. The "natural is better" heuristic is particularly relevant to people's acceptance of new food technologies and their appreciation of food products.

Moving towards a more sustainable, more reliable and safer food system is hard to imagine without more and more new food technologies. Thus, general skepticism about innovative food technologies will remain a long-term problem. The main question is for what purpose the technology is applied, and not whether the innovative technology is used. Society needs to move towards healthier eating, but food technology needs to be part of this trend, not seen as a barrier.

The goal of the food industry today is to produce safer, more nutritious and tastier foods, and to extend their shelf-life. Consumers are suspicious of food production, preparation and processing methods, especially those with potential contaminants or chemical residues from production. Frequently, food manufacturers are not considered reliable sources. Partially, this may be due to the reluctance of manufacturers to share all information about the manufacture of products and protect intellectual property through patents and thus maintain a competitive advantage. To increase confidence, it is necessary to better inform the consumer about what procedures the ingredients involved are subjected to and why.

Innovative food processing technologies face implementation challenges, and factors affecting consumer and other stakeholder acceptance must be considered in the decision-making process when introducing these technologies. It should be borne in mind that the perception of risks by consumers differs from the risk assessments made by experts. Consumer fears about the introduction of more and more new technologies are causing the industry to be cautious, bordering on neophobia, even if these technologies produce higher quality products with less environmental impact.

The sophistication of food processing enhances consumer convenience, expands diet choices, and offers a variety of organoleptic properties to meet consumer desires and needs. However, consumer confidence in the food industry remains extremely low, which, according to some authors [4], is due to a lack of transparency regarding how food is prepared and processed. The introduction of technologies where, due to a lack of knowledge, consumers cannot weigh the risks versus the benefits (e. g. exposure to radiation) undermines the credibility of the food industry, contributing to the positioning of consumers of "overprocessed" foods as unhealthy. Any claim that the use of food processing and/or improvement of palatability through the application of innovative technologies raises consumer concerns about food safety. Such claims must be scientifically proven, and food manufacturers must make efforts to ensure that consumers know how their products are processed within the facility.

Work [5] considers the influence level of neophobia of food technologies, socio-economic variables, information about new food products and applied technologies on the attitude of consumers to the use of food products in relation to the positive impact on the environment and consumer health. It is emphasized that education and, above all, neophobia of food technologies and information are critical factors hindering the widespread introduction of new food technologies and preventing the failure of innovations in marketing strategies.

Important determinants of risk perception associated with new foods are dichotomous assessments of potential hazards: technological or natural origin; acute or chronic manifestation [6]. This paper presents an analysis of the results of a case study that examines how hazard ratings affect people's perceptions of risks and benefits, as well as related attitudes and behaviors. Analysis of acute and chronic cases shows that quantifying the relationship between risk perception and consequences is important for both acute and chronic food safety. Technologies used in food production tend to be potentially associated with a higher level of risk perception connected with its perception as unnatural. However, for some risks (such as those associated with biological irreversibility), moral or ethical considerations may be more important determinants of consumer response than the perception of risk or benefit.

The main purpose of this review paper is to study the socio-ethical problems and resulting neophobia on specific examples of innovative food processing technologies that may be more important for consumer acceptance of new foods.

2. Innovative technologies

2.1. Nanotechnologies

Food nanotechnology is developing as a rapidly growing industry with its wide application from primary food production at the agricultural level, to food production, packaging and transportation of finished products [7,8]. Nanotechnology is constantly evolving as a broad area of research in the efficient processing of raw materials, the development of functional products, food preservation, packaging and storage. Food producers, with the proper use of advances in nanotechnology, can gain a competitive position in the markets.

Trends in the field of nanotechnology are discussed in [9], as well as challenges and promising opportunities in the food industry, identified in recent studies. The toxicological basis and risk assessment of the use of nanomaterials in new food products are discussed. The potential prospect of using biosynthesized and bioinspired nanomaterials for the sustainable development of the industry is emphasized.

Various forms of nanoengineering structures used in food nanotechnologies to regulate the characteristics of ingredients and finished products and their application are considered in [10]. It is noted that purposefully created nanostructures improve the solubility of food ingredients in vivo, as well as increase their bioavailability and controlled release at the target site. Such nanostructures can also serve as anti-caking agents, nutraceutical delivery systems, etc.

The characteristics of modern food nanotechnologies, as well as their existing and possible future applications, are highlighted in a review paper [11]. It is stated that as research in the field of food nanotechnologies develops, public concern about the safety of such products intended for human consumption and use is increasing. As a result, before the commercialization of products made using nanotechnology, a careful assessment of potential risks to human health and the environment is required.

Work [12] briefly outlines the features of "green" nanomaterials, their impact on the environment, legal issues, health and safety issues, and their purpose in the agricultural sector. Socio-ethical and environmental concerns, health and safety risks, issues related to obtaining goods through intermediate consumers, and market demands may prevail in the production and creation of green nanomaterials.

Review [13] examines the current applications of nanotechnologies for packaging, processing and improving the nutritional value and shelf-life of food products. Recent advances in nanotechnology are designed to provide innovative applications in the food industry. These nanomaterial devices play an important role in the food industry, including food packaging, processing and storage. Nanomaterials also increase the shelf-life of foods by protecting them from moisture, gases and lipids. Nanotechnology still has great potential and new applications are being explored in various areas of the food industry. It is clear that security issues are emerging and will need to be carefully considered and addressed in the future.

Paper [14] discusses the issues of understanding and supporting efforts aimed at the implementation of "responsible innovations". It is noted that "responsible innovation" is characterized by four integrated aspects: anticipation, reflexivity, inclusion and response.

The general concern of researchers regarding the potential negative consequences of the use of food nanotechnologies for human health and the environment [15] attracts public attention. Publications related to such research have led to media sensational reports about the possible negative health effects of nanotechnologies and, as a result, their negative perception by potential consumers. It is obvious that this social problem must be solved before the commercial operation of the planned food nanotechnology and the market entry of finished products.

Indeed, the negative impact of nanomaterials can be harmful to the product manufacturer, its consumer and the environment and may increase potential risks. For this reason, it is necessary to assess the potential risks arising from the interaction of nanomaterials with biological systems, people, and the environment [16,17,18].

The use of nanofertilizers and nanopesticides in agricultural production can provide targeted and controlled release of agrochemicals to achieve their maximum biological effectiveness without overdosing. However, this is of concern to agricultural workers who may be exposed to such xenobiotics during their work. The limited knowledge of workers about the biosafety of nanomaterials, adverse effects, their fate, acquired biological reactivity after dissemination in the environment does not provide the necessary protection, and requires a careful assessment of possible nanoagricultural risks. Therefore, the determination of the danger of nanomaterials and the levels of their impact is necessary throughout the entire life cycle of products, as well as the assessment of those physicochemical characteristics that affect the toxicity of nanomaterials and possible interactions with accompanying agents of agricultural systems [19,20].

Food nanotechnologies can allow the modification of many food characteristics such as appearance, taste, aroma, texture, color fastness, processability and shelf-life stability, leading to the creation of a large number of new food products. Nanotechnology can also improve the water solubility of product, thermal stability, and oral bioavailability of various functional compounds [21,22,23,24]. Realizing the potential of nanotechnology, the world's leading food companies are increasingly interested in research and development in the field of nanotechnology, which is realized through their large investments in nanotechnology.

At the same time, there is growing concern that the use of nanomaterials in the food industry may lead to nanoparticles gaining access to tissues in the human body, leading to the accumulation of toxic contaminants and therefore adversely affecting human health [25]. In the production of food of animal origin, there are several possibilities for the use of nanotechnology — in animal husbandry, processing of animal products, and manufacture of food products, their packaging and storage. The direct use of nanomaterials in various stages of food production, as well as uptake from the environment, can lead to the presence of such nanomaterials in the final product. Aerosol nanomaterials can enter the human body through the lungs, and nanomaterials in the form of liquids and gels can enter the body through the skin and mucous membranes, which represent possible long-term risks to the health of consumers and workers in occupational situations.

As long as the nanoparticles remain bound, their impact is limited or very low. However, the migration of nanoparticles included in the food material is a high risk for humans. Studies have shown that nanoparticles, characterized by increased reactivity and greater ability to cross membrane barriers and capillaries, can lead to various toxicokinetic and toxicodynamic disorders. Some nanoparticles interact with proteins and enzymes, which leads to the destruction of mitochondria and induces apoptosis after the introduction of nanoparticles [26]. Intermediates formed in the dynamic process of transformation of nanomaterials increase the complexity of assessing their toxicity [27].

Research [28] attempts to link the level of food neophobia, a personality trait by which people can be divided in terms of their propensity to accept or avoid new foods, to the acceptance of nanotechnologies applied to food production. It is noted that consumers show a certain reluctance to buy products made using nanotechnology. Food nanotechnologies are extremely complex and, with indecisive consumers, this may be enough to prevent their benefits from being realized [29,30].

Although the proposed applications of nanotechnologies are wide and varied, all developments are met with some caution, while progress in the use of nanotechnologies can be hampered by a lack of effective management and potential risks [31]. In this regard, to assess the risks of producers and consumers, analytical methods for the detection and characterization of nanomaterials in complex food matrices and their toxicological data are needed [32].

The problem of the methodology for assessing the safety of nanomaterials is in the focus of attention of many international and national organizations, including the Commission of the European Union. At the end of 2018, the European Food Safety Authority developed a new "Guidelines for Risk Assessment of Nanoscience and Nanotechnology in the Food and Feed Chains: Part 1, Human and Animal Health" [33]. This guide takes into account new developments that have occurred since the publication of the previous guide in 2011.

The risk assessment of the use of nanomaterials and nanotechnologies contains four main components: hazard identification, hazard characterization, exposure assessments and risk characterization. A nanomaterial can be extremely hazardous but have a small potential risk at low exposure, and the risk can be large when the nanomaterial has limited hazard but high exposure.

The risks of nanotechnology commercialization in the food industry are not limited to risks to human health and the environment. Equally important are the socio-cultural and historical conditions that determine the attitude of people to new technologies and their applications and are important determinants of the successful implementation and commercialization of nanotechnologies [34]. It is important to pay attention to public opinion regarding nanotechnologies in the food business at the stage of product development in order to avoid some of the pitfalls that occurred during the development of the technology of gene modification of organisms [35,36].

Only careful consideration of the implications of their use in each specific case at the development stage before products are placed on the market can provide a basis for assessing the conceptual risks, including socio-ethical ones, when using nanomaterials and nanotechnologies in food production.

The widespread use of nanotechnologies and nanomaterials in the food industry should be viewed as the development of modern technologies with further significant growth. It is expected that food products and their packaging obtained using nanotechnology will be increasingly available and in demand by consumers around the world in the coming years.

2.2. Technologies of genetic modification

The food industry is increasingly using agricultural products, raw materials and various ingredients obtained using genetic modification technologies. The use of such technologies in Russia is regulated by federal law No. 86-FZ[1], 1996 "On state regulation in the field of genetic engineering activities", adopted in 1996. However, at present, gene editing technologies that are not regulated by this law are becoming more widespread.

Genome editing technology is rapidly spreading and revolutionizing the fields of agriculture and the food industry. Unlike traditional GM technology, which adds foreign DNA to the recipient's body, genome editing replaces mutated or otherwise unwanted DNA bases, thereby altering the overall suitability, productivity, quality, and utility of the recipient as necessary. At the same time, it is almost impossible to determine whether the DNA of a plant or an animal has been edited, because the changes that occur are indistinguishable from natural mutations.

Various regulatory authorities declare these "edited" organisms and foods safe, and they are exempt from testing and labeling requirements. However, opponents of GM technologies speak out against these forms of genetic modification. Review [37] discusses the current data on the global and European introduction of GE crops, as well as the potential impact of a new wave of crop development on agriculture. It assesses how the European Union (EU) views GM crops and looks at the future of both genetic modification (GM) and genome editing (GE) in the EU.

Genome editing technologies can help address the challenges of sustainable development, global food security and climate change. However, despite their potential, the adoption of these new technologies has been slowed down by the uncertainty surrounding the regulation of genome edited crops. Misleading online articles questioning the safety and ethics of these "new" biotechnological foods can also lead consumers to be reluctant to take them. Consequently, Europe's ambivalent attitude towards biotechnological crops may hinder their adoption by potential growers who could benefit greatly from the technology.

Article [38] analyzes the grounds and consequences of the decision of the Court of Justice of the European Union. The Council of State of France has asked the Court of Justice of the European Union to determine, in substance, whether organisms obtained by mutagenesis (that is, gene editing) are genetically modified organisms (GMOs). The Court held that the existing Directive also applied to organisms produced by mutagenesis techniques that appeared after its adoption.

However, in response to the Court's decision, the US Secretary of Agriculture issued a statement criticizing the decision. The statement, in particular, says, that "public policy should encourage scientific innovation without creating unnecessary barriers or unduly stigmatizing new technologies. Unfortunately, this decision of the Court is a failure in this regard, as it narrowly views new genome editing techniques as subject to regressive and outdated European Union rules governing genetically modified organisms."

Papers [39,40] provide an overview of the complexity of the study and interpretation of global public opinion about GM foods, in which the authors noted a negative attitude towards genetically modified foods in Europe. Surveys conducted in recent years have found that the percentage of respondents opposed to GM foods was on the rise, and significant efforts were needed to reverse this trend.

Paper [41] presents the results of a sociological study of the perception by the Chinese population of the use of genetic modification of a wide range of agricultural crops in food production. As a result of the survey, 11.9% of respondents gave a positive answer, 41.4% — neutral one and 46.7% have a negative attitude towards genetically modified foods. 13.8% of respondents considered GM technologies to be a form of bioterrorism directed against China. A minority of respondents (11.7%) stated that they understood the basic principles of GM technology, while the majority of them were either "neutral" or "unfamiliar with GM technology". The percentage of respondents who trust the government and scientists was only 11.7% and 23.2%, respectively. It is noted that until public doubts about GM foods are addressed in a balanced and evidence-based manner, it will be difficult for China to develop sound policies and programs that will benefit the agribusiness and consumers.

The use of enzyme preparations (EP) in the food industry is constantly growing. These EPs are mainly obtained by microbial fermentation, for which both wild-type and genetically modified strains are used. The yield of EP production can be increased by optimizing the fermentation process, either using genetically modified strains of microorganisms, or through the production of recombinant enzymes. Work [42] provides a general overview of the various methods used for the EP production and how the use of GM can increase production yield. The need to develop appropriate methods for detecting and identifying the presence of a gene modification in enzyme preparations that are used in food production is emphasized.

Study [43] was conducted to examine the factors of the conceptual model that influence the perception of social risks of acquiring GM foods by consumers. Confirmatory factor analysis and reliability tests (Cronbach's alpha test) were used to identify the most cost-effective models that are best suited for social risk perception of GM foods. It is noted that the psychological attributes of risk, the perception of social benefits, attitudes towards the use of technology, the level of religiosity and moral and ethical beliefs were the most powerful predictors of the perception of social risk. The perception of social benefit also had an indirect impact on the social risk assessment of GM foods [44].

Only time will tell if GM foods or genome-edited organisms are the best solution to achieving food safety, security and sustainability. At least for GM foods, the absence of any credible, documented side effects is reassuring.

[1] Federal law No. 86-FZ, 1996 "On state regulation in the field of genetic engineering activities", Retrieved from https://fsvps.gov.ru/ru/fsvps/laws/4311.html Accessed September 15, 2022.

2.3. Non-thermal technologies for inactivation of microorganisms

Thermal processing technologies have historically been the most common microorganism inactivation method used in the food industry to ensure food safety and extend shelf-life. Traditional thermal food decontamination technologies have certain limitations and disadvantages, such as changing product quality, environmental impact, carcinogenicity, potential and/or lower consumer acceptance. However, due to the increased consumer demand for more natural and healthier food products, the possibilities of using non-thermal processing technologies are being intensively explored.

The most common non-thermal food processing technologies for the purpose of inactivation of microorganisms usually include [45] the following methods: high hydrostatic pressure, pulsed electric fields, high-intensity ultrasound, cold atmospheric plasma, ultraviolet radiation, pulsed light, ionizing radiation and oscillating magnetic fields, which have the ability to inactivate microorganisms to varying degrees. These innovative technologies have recently become industrial methods for pasteurizing meat products and semi-finished products, fish and seafood, dairy and vegetable products, as well as ready meals.

The studies, the results of which are given in [46], show that among non-thermal methods of pasteurization of products, the use of high hydrostatic pressure in the USA is 35.6%, pulsating electric field — 20%, cold atmospheric plasma — 14.1%, oscillating magnetic fields — 14.0%. There are also technologies that are still under development and are currently being applied to extend the shelf-life of certain foods while preserving their natural nutrients.

Work [47] considers the recent use of non-thermal disinfection technologies in the food industry, as well as the mechanism of their action. In addition, it analyzes the potential prospects for a combination of non-thermal processings used in the food industry, which can not only overcome the disadvantage of one technology, but also provide processing efficiency at a lower intensity.

2.3.1. High hydrostatic pressure processing

The use of high hydrostatic pressure in food production technologies was proposed a long time ago, at the end of the 19th century [48]. Even then, it was noted that milk processing at a pressure of 670 MPa for 10 minutes at room temperature sharply reduces its bacterial contamination. Moreover, in meat processed at a pressure of 530 MPa for 1 hour, there was a slight increase in the number of microorganisms only after three weeks. Despite the positive results obtained, interest in this technology faded for almost a hundred years, mainly due to the lack of suitable equipment until that time and the very high cost of its development, manufacture and operation. The general development of mechanical engineering and electronic technology has made it possible to develop and introduce into commercial operation various types of specialized equipment for processing food products with high hydrostatic pressure (HHP). However, its wide distribution is still delayed, more studies of the mechanism of action (HHP) on foods are being carried out.

Initially, it was noted that high (HHP) is detrimental to microorganisms, and therefore the focus of the study was to use this effect for non-thermal pasteurization and/or sterilization of products. Similar studies, but in finer detail, continue today. Work [49] is devoted to the analysis of the impact of this innovative non-thermal processing technology on the quality of food products. It is shown that this technology is currently the most popular, as it allows one to simultaneously preserve the nutritional and organoleptic characteristics of products and inactivate microorganisms in them, thereby extending the shelf-life of products.

Article [50] reviewed recent research results on the use of HHP to improve food safety by non-thermal inactivation of *Salmonella* spp. It is noted that there are certain limitations when using this technology. The composition and condition of food significantly affect the effectiveness of HHP. A reduced exposure effect has been observed for some foods high in fat, protein and sugar. In addition to ensuring the microbiological safety of food products, HHP technology can also be used to improve their techno-functional properties. A review study [51] considers the prospects for the use of HHP in the development and manufacture of products for a healthy diet. It has been shown that HHP promotes the biosynthesis of g-aminobutyric acid in food materials, preserves immunoglobulin components in dairy products, increases the content of resistant starch in cereals and reduces the glycemic index. Because HHP causes physical damage to the structure of foods, it can also be used as a synergistic extraction technology to improve the extraction efficiency of functional components, thereby reducing their extraction time. Potential synergistic effects of the use of HHP for the processing of various foods are also reported in [52]. The ability to use three parameters at the same time: pressure, temperature and time can be optimized for the development of food products with special properties.

The focus of [53] is on the use of HHP for gelling, high-pressure infusion, and high-pressure impregnation, methods with great potential for improving food quality. High pressure processing still has many unexplored opportunities for improving food quality. As noted in [54], one of the reasons for the lack of widespread use of HHP for the processing of liquid dairy products may be that this processing adversely affects many components of milk, especially protein and mineral balance, and causes changes in the functional properties of such products. At the same time, HHP processing is a potential technology in the dairy industry for cheese production due to its positive impact on rennet coagulation time, cheese yield, ripening characteristics, cheese shelf-life, cheese functionality and development of new textures. In some cases, such as for air-cured meat products, HHP is the only possible pasteurization process that has minimal impact on appearance, taste, texture, and nutritional value.

The current commercial success of HHP processing can mainly be attributed [55] to the ability to provide food products with superior organoleptic quality, high nutritional value and biofunctional properties with extended shelf-life compared to corresponding thermally processed food products. In general, it was noted that HHP — food processing technology has a significant impact on the environment, its implementation in the production process can lead to significant water and energy savings, efficient use of packaging material and can significantly reduce food waste due to the increased shelf-life of processed products.

2.3.2. Electromagnetic processing

Pulsed electric fields (PEFs) are a new and promising non-thermal food processing technology that is evolving from laboratory and pilot plant levels to industrial levels. As work [56] shows, the use of PEFs for food pasteurization is an attractive and effective non-thermal technology that can increase the functionality and efficiency of microorganism inactivation.

Work [57] provides a systematic review of PEF-based technologies used in China for food processing. It has been shown that PEF effect on products in isolation or in combination with other methods allows not only inactivating microorganisms and promoting the extraction of active components, but also modifying biomacromolecules, enhancing chemical reactions and accelerating the maturation of fermented foods. The effect of an electric field is manifested mainly in the permeabilization of biomembranes, the occurrence of electrochemical and electrolytic reactions, the polarization and rearrangement of molecules, as well as a decrease in the activation energy of chemical reactions. It is noted that there are conflicting results using this technology, in particular when acting on enzymes.

The use of PEFs in the manufacture of food products attracts considerable attention as an environmentally friendly technology for improving the technofunctional properties of dairy and vegetable proteins. Work [58] discusses the effect of PEF processing on the structure of milk and vegetable proteins, as well as protein-polysaccharide complexes, and changes in their technofunctional properties (solubility, gelation, emulsification, and foaming). This paper also presents the main problems and possible trends in the use of PEFs in the food industry.

Work [59] reviewed the use of PEFs for the processing of proteins and bioactive peptides in foods, including protein extraction, hydrolysis, inactivation or activation of enzymes, and enhancement of the biological activity of peptides. It is noted that the effect of PEFs on proteins is mainly associated with changes in their secondary and tertiary structures.

Study [60] is aimed at evaluating the effect of preprocessing with a pulsed electric field on mass transfer, microstructure, and palatability of beef during marinating. It is shown that such processing allowed reducing the pickling time by 33% while improving the tenderness of the finished product.

At the same time, the rejection of traditional thermal methods of food processing and their replacement with innovative technologies leads to consumer distrust in the quality of the finished product and the product compliance with expectations. In addition, PEF technologies require the development, creation and qualified maintenance of complex and high-tech equipment using very high electrical voltage.

Many researchers carry out the study of the mechanisms of PEF action on food products and the results of such studies are increasingly used in the food industry. Much less work is devoted to studying the effect of a pulsed magnetic field on food products. As work [61] shows, the bactericidal ability of a pulsed magnetic field is provided by the effects of electromagnetic induction, the effects of Lorentz forces, and the effects of ionization. Compared to the use of PEFs, this technology is less dangerous for personnel.

Electromagnetic food processing methods can be part of other, more complex, combined methods. Work [62] critically reviews and summarizes research on decontamination of dry food surfaces using cold atmospheric plasma excited by an electric field and low-energy electron beam irradiation of foods, which have demonstrated the potential to solve certain processing problems.

Of greatest interest is irradiation with an electron beam with an energy of more than 10 MeV, as well as bremsstrahlung generated by electron accelerators with an energy of not more than 5 MeV. Electron accelerators also have advantages over other methods. This is a short exposure time (a few seconds compared to minutes and even hours in some cases). Higher efficiency, which, depending on the material being irradiated, is 40–80%. In addition, they are more economical and are subject to less stringent requirements for radiation protection of service personnel [63]. Furthermore, microorganism inactivation mechanisms using these technologies, product-process interactions, current limitations and scaling-up potentials are proposed, and research trends and needs for both technologies are discussed.

2.3.3. Irradiation technologies

The use of various types of radiation for the disinfection of products has been known for a long time and, apparently, goes back to the use of direct sunlight for these purposes. Ultraviolet (UV) radiation is still widely used in the food industry to inactivate microorganisms. This is an effective method of inactivating microorganisms in food products, damaging their DNA and/or disrupting the activity of cellular enzymes and the integrity of the cytoplasmic membrane. Along with the use and improvement of known methods of UV processing of products, new methods are being developed. The development of new methods is aimed at eliminating the main drawback of the use of UV processing — the change and often deterioration of the physicochemical and organoleptic properties of products. However, research in this direction continues. Work [64] shows that the processing efficiency depends on the process parameters (exposure time, UV dose, wavelength), product type (chemical composition, viscosity, turbidity, opacity and roughness), equipment (shape and geometry) and characteristics microorganisms (species, strain, growth phase and recovery conditions). Under optimal conditions, UV processing has minimal effect on product properties. The use of UV processing of products in most cases does not cause negative emotions in the consumer due to its wide distribution, but when using it in production, caution and careful observance of safety regulations are required.

However, UV radiation is not able to penetrate deeply into the product and inactivate microorganisms inside the product; most often, only its surface is treated. Therefore, as numerous studies conducted over many years show [65], the use of other types of radiation is more effective both in terms of inactivation of microorganisms in products and in terms of production efficiency. These types include irradiation processes using ^{60}Co or ^{137}Cs radionuclides, as well as electron and X-ray beam generators (GOST ISO 14470–2014[2]).

One of the first works on the use of ionizing radiation in the food industry was published in 1950 [66] and already in the Soviet Union in 1958, and the use of ionizing radiation to prevent the sprouting of potatoes was officially allowed in Canada in 1959.

Work [67] emphasizes that any new food processing that includes the procedure of irradiation presents a serious problem in the response of potential buyers. To increase the acceptability of these technologies by consumers, not only strong scientific evidence demonstrating the safety of irradiated food is needed, but also information, labeling and explanation of this particular technology. New marketing strategies based on positive reports of food irradiation may encourage consumers to be more receptive to safety-oriented high-quality irradiated products.

A review article [68] discusses the various implications of food irradiation in terms of nutritional value, shelf-life extension, toxicological aspects, food irradiation legislation and global acceptability. It is noted that not all food products are suitable for irradiation. Certain food components, such as vitamins and enzymes, are affected by radiation exposure. Therefore, recent trends in food irradiation research show an increase in work on radiolytic products formed after food irradiation.

Numerous studies contribute significantly to the understanding of the complex nature of irradiated foods, the growing importance and conflicting opinions of consumers. Thus, study [69] extends the theory of prerequisites for planned behavior to analyze independent determinants and the impact of risk and trust on consumer perception of irradiated products using the example of Australia. This study as a whole made a significant contribution to the identification of areas of preference for irradiated foods. It is one of the first to assert and show the importance of such inputs as risk and trust. It also defines the moderating role of concerns about the need to disclose information

[2] GOST ISO 14470–2014 "Food irradiation. Requirements for the development, validation and routine control of the process of irradiation using ionizing radiation for the treatment of food". Moscow: Standartinform, 2015. — 22 c.

that is key to making informed decisions about irradiated food.

Work [70] noted that consumers often exhibit a strong aversion to highly processed foods and unfamiliar and artificial-sounding innovative food technologies. This study highlights the importance of terminology when communicating with consumers about the use of innovative food decontamination strategies. Therefore, food irradiation is a prime example of how important it is to take into account the consumer's perspective before implementing a particular food processing technology, in addition to evaluating cost-effectiveness and efficiency. This study also highlights the importance of consulting social scientists before implementing innovative food technology.

Another problem with irradiation technologies is the current lack of an analytical method that can be used to control all types of food and detect the use of irradiation. It is noted in [71] that the determination of the difference between irradiated and non-irradiated food products remains an unsolved analytical problem. In fact, most chemical compounds resulting from irradiation processing are not unique products of radiolysis and therefore are not adequate markers for detecting ionizing radiation applications. The possibility of detecting food products irradiated with low doses is still doubtful, and research efforts can be directed to the detection of ingredients irradiated at doses below 1 kGy and included in non-irradiated foods.

The aim of the papers [72,73] was to investigate the willingness of consumers to accept irradiated food and to identify the main factors associated with both socio-ethical characteristics and the perceived risk of consumers in relation to food processed using irradiation technologies. As a result of these studies, it was determined that the acceptability of irradiated foods for consumers depends mainly on the perceived health risk resulting from their consumption. Equally important are socio-economic factors such as age, monthly income of consumers and the geographic area in which they live. These studies present some interesting proposals for both policy makers and managers. First of all, it is the need for an effective advertising campaign aimed at educating consumers about the principles, goals and benefits of irradiation technology, as a new method of food processing, offering consumers greater guarantees in terms of food safety and food safety. It is also proposed to replace the term "food irradiation" with "cold pasteurization". Being the same technology, it could change consumer attitudes towards processed foods, increasing the propensity to accept or buy irradiated foods. (Similar to the replacement in medicine of the term "X-ray tomography" with the term "Computed tomography".)

Most ordinary consumers still consider irradiation to be a dangerous method of food processing. People associate ionizing radiation with cancer and consider irradiated food no less dangerous. This is a delusion that must be eradicated by proper education. All international agencies such as the WHO and the IAEA have endorsed food irradiation as a safe and effective method of ensuring food safety. In addition, the use of this technology can help to solve the ethical problem associated with food waste, which can be eliminated by processing with ionizing radiation. In fact, food waste is an issue of great importance for global food security and natural resource use that is directly connected to environmental, economic and social impacts.

2.4. Additive technologies

Additive technologies are methods of layer-by-layer addition of materials during the manufacturing process of a product, which make it possible to create different types of layers with different compositions, properties, and topologies. Additive technologies are increasingly used in the industrial manufacture of food products and this is due, primarily, to the general digitalization of technological equipment. Different combinations of ingredients and the design of the food layers used can impart new tastes, aromas and textures not found in conventional food preparation processes. At the same time, one of the main goals of using additive technologies in the food industry is not just a new industrial processing, but adaptation to the concept of personalized nutrition in accordance with the needs of various consumer groups.

The most rapidly developing and promising additive technology for the food industry is 3D food printing. A food product made using 3D printing is a random (at the choice of the product designer) food system created from discrete elementary miniportions of various fats, proteins, carbohydrates, and other components arranged in the order established by the designer. At its core, the use of 3D printing in the food industry marks its gradual transition to the development and production of **digital food systems**. Understanding this transition stimulates fundamental and applied research in this direction.

The state of science in the field of applied methods of additive technology for food production is considered in work [74]. It was noted that the main task for the coming years would be use of 3D printing for the manufacture of meat products or products containing alternative protein sources that retain the desired structure without the need for additives. It also considers the use of alternative protein sources, such as animal by-products, to address food sustainability and industry sustainability issues.

In addition, the possibilities of 3D printing technology for meat products are considered in works [75, 76]. These reviews assess the potential of 3D printing for meat processing and the elementary aspects that affect the printability and post-processing capability of 3D printed meat products. It is noted that the combination of nutrient-balanced ingredients and internal structures allows the creation of three-dimensional products from several components that meet the individual characteristics of consumers, such as difficulties with chewing and swallowing.

An important factor in consumer acceptability, in addition to appearance and taste, is the texture of foods. A review article [77] studied the existing work on 3D printing of food products and discussed developments related to the design of food textures. The advantages and limitations of 3D printing in the food industry, the possibilities of printing from various materials and textures based on mathematical models, as well as future trends in 3D printing, including numerical simulation, are discussed. The key issues for the mass adoption of 3D printing are also discussed in detail. It is emphasized that existing studies of consumer perception and sensory analysis of printed food products give conflicting results. Resistance has been reported by many consumers of 3D printed food products due to their appearance, the source of the food material, the visually perceived sensory characteristics, and the perceived unnatural origin of the printed structures. Most study participants showed better susceptibility to familiar foods. The authors noticed a positive change in opinion with the increase in the amount of information provided to consumers of these products. An exception was observed in people who already had a prejudice against 3D printing and suffered from food neophobia, where communication was ineffective and even strengthened their opinion.

Review articles [78,79] deal with the results of 3D food printing and recent developments in food texture design. The advantages and limitations of 3D printing in the food industry are discussed, as well as trends in 3D printing, including cooking technologies with food printers. It also discusses in detail the key problems hindering the mass adoption of 3D printing. It is noted that the acceptance of 3D printing by the widest consumer depends on people's awareness of this technology and its benefits. Further information dissemination about the potential of 3D printing could help increase consumer acceptance of this new technology.

Paper [80] provides an overview of the properties of consumables for 3D printing and their impact on printing processes. It also highlights the wide range of applications of 3D printing in the food industry and some of the challenges that arise when implementing into production. A specific feature of the use of 3D printing is noted — this is the possibility of piracy of digital recipes and computer control programs, which will become a problem as the technology and its applications expand. 3D food printing could become as disruptive as the personal computer and the Internet.

A wide variety of options for 3D printing, preparation of initial components, composition and shape of the finished product are considered. Thus, in work [81], the focus is on the relationship between the properties of starch-containing food materials and 3D printing by hot extrusion. It also discusses the influence of material properties (rheology, adhesiveness, thermal properties, microstructure and component interaction) on printability. In addition, the influence of additives (hydrocolloids, lipids, fiber, protein, salt, etc.), processing methods and process parameters on printing is considered.

A brief critical assessment of methods for improving the characteristics of 3D printed products is presented in review [82]. It also provides recommendations for future research and development in the processing of 3D printed products, including their post-processing, such as drying, frying, baking, cooling, sterilization, etc., which is critical for wider industrial applications of this rapidly developing technology.

In work [83], it is noted that 3D food printing technology, as a new intelligent technology, due to its built-in capabilities, can support a sustainable supply chain. At the same time, stakeholders need technical know-how regarding 3D printing technology, well-supported by the legal framework for clear ownership of intellectual property rights. In addition, manufacturers must have focused and clear strategic planning in a sustainable supply chain.

The possibilities of using components with a high protein content and biological value, a good amino acid profile and functionality based on algae, insects, plants, fungi, and microbial proteins in 3D food printing technologies are being actively explored [84]. It is noted that the use of 3D printing of food products and artificial intelligence in combination allows the development and manufacture of personalized products with high nutritional value and a wide demand potential.

Various technologies used in food 3D printing are discussed in work [85] from a commercial point of view, i. e. their use, availability and reliability should be considered from a business point of view. In addition, 3D printed food products, their position in the market, demand for them, as well as supply in the conditions of large-scale and medium-scale production are considered.

People's attitudes towards new technology, critical factors influencing consumer behavior, and, finally, the impact of 3D printing on social, economic and environmental changes are constantly in the field of research. 3D food printing technology is fundamentally redesigning food production, thereby influencing many areas of everyday life. Study [86] attempts to determine the behavior of people in relation to 3D printing technology, to assess their awareness and how familiar they are with this new technological innovation. According to the authors, in the near future, a desktop 3D printer will be necessary for every home and office.

With the development of additive technologies, 3D printing is gradually transforming into 4D/5D/6D food printing technologies. In essence, 4D printing adds a temporal dimension to 3D printing due to the programmed change in the properties of a food product over time or under the influence of initiating external factors. 4D printed products undergo some programmed structural changes over time. Usually, some environmental factors are required to trigger this transformation. For example, moistening or heating, some products may change shape, others may change texture, and some products may allow consumers to customize them to their liking [87]. This paper critically discusses aspects of the recombination of various food materials and the reasons for the change in color, shape, taste, and nutritional properties through 4D food printing. The key to the success of 4D food printing and various solutions to related problems are identified and analyzed. 4D food printing is fully consistent with the concept of "flat packaging", i. e. in production, an initially heavily deformed product is printed and packaged, which, after removing the packaging and some processing, and takes the desired form. This 4D printing capability reduces shipping costs and storage space.

In recent years, there has been a significant increase in research in the field of 4D, as well as 5D and 6D printing of food products [88 56]. The current applications, advantages, limitations and challenges of 4D food printing are reviewed and summarized. In addition, the principles, current and potential applications of the latest additive manufacturing technologies (5D and 6D printing) are reviewed and discussed. Moreover, it is noted that 5D and 6D printing can in principle print very complex structures with increased strength and less material than 3D and 4D printing. In the future, these new technologies are expected to lead to significant innovations in all areas, including the manufacture of high-quality food products that cannot be made using existing processing technologies.

Recent advances in the field of 2D/3D/4D/5D printing with rheologically stable components for food products, including food decoration, food personalization, and food analytics, are summarized [89]. In addition, perspectives (such as 6D printing) and key issues (rheology with interdisciplinary integration) for printing with food components for creative food production are proposed and solved.

The perception of new food technologies is fluid. Future research should explore how consumers perceive different innovative technologies and what aspects of these technologies most strongly influence their adoption. The final step will be to gain consumer acceptance of food products that are complex digital food systems printed using multidimensional printing. If consumers are properly informed about the methods used and the benefits offered, then we see no real barriers to wider acceptance of these technologies, especially among future generations.

When food products begin to enter the market using innovative technologies in their manufacture, the media actively begin to discuss their benefits and potential dangers. This has been the case with the use of ionizing radiation, nanotechnology, genetic modification, 3D printing, etc. At the same time, mass consumers mainly rely on cognitive sensations or heuristics, rather than scientific knowledge, to understand problems on which they have a low level of knowledge. This heuristic may include predisposing factors such as ideological beliefs or value systems, as well as short-term reference points provided by the media or other sources of information. Religious filters are also an important heuristic for food nanotechnologies — this is the level of personal perception of new scientific achievements directly related to the consumer, associated with the level of his/her religiosity. The positive attitude towards innovative technologies among less religious respondents is higher than for religious consumers. Such moral views are directly correlated with the levels of religiosity in each country. Thus, when commercializing innovative food technologies, it is necessary to consider the risks associated with the socio-cultural and historical characteristics of the potential market [90].

The commercialization of innovative food technologies is also complicated by dynamic sociocultural shifts in societal values. For example, emerging consumer preferences for environmentally friendly production systems [91], localized foods [92], or improved animal welfare standards [93]. All this makes it difficult to create a long-term commercialization program for innovative food technologies.

The future of innovative food technologies largely depends on the opinion of consumers. This is due to the fact that if consumers do not accept the proposed food product using a particular technology, then it ceases to be used in manufacture after some time. It is obvious that consumer expectations are not only in terms of safety and health benefits, but also in such requirements as improved taste of the product, consistency, appearance, aroma, etc. Consumers have many expectations, but in general they are mainly expected to be fully sustainable not only with respect to human health, the environment or production methods, but also with regard to animal welfare. For this reason, companies or products that will win in the food industry in the future are likely to come close to these requirements or expectations.

3. Conclusion

While developments in innovative food technologies are breaking new ground every day, there are still many challenges and opportunities to improve existing technologies, as well as concerns about the potential impacts of new technologies. The more global, dynamic and complex food systems become, the more innovative technologies are used in the production of food, the more various problems arise that need to be addressed to allay consumer fears. Even with the advent of new food technologies, the challenges of creating a healthy and sustainable food sector remain. Transparency of safety and environmental impact issues should be a priority when developing and using innovative technologies in the production of food systems, so mandatory testing of new products before they are released to the market is of the critical importance.

The public is often less aware of innovative food technologies, while attitudes change depending on how these technologies are used and promoted. The conflict seems to be that the public wants to be informed about the status of food technologies being used (especially the development of related new products); while food manufacturers prefer the opposite, as their technology is confidential. Proper public information is critical to the long-term success of introducing and developing innovative technologies in the food industry. Not only the development of innovative technologies and the release of new products are important, but also the legislative regulation at the state level of the use of these technologies, which ensures food safety with minimal environmental impact.

It is to be hoped that the intensive development of information technologies, together with a synergistic set of innovative food technologies, some of which are considered in this paper, will allow making a gradual transition to the production of **personalized digital food systems** that have functionality, good taste, and safety with minimal negative impact on the environment.

Future research should aim to quantify the links between the economic impacts of innovative technologies and health and environmental risk factors, considering the preferences of different consumer categories.

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Completely prepared the manuscript and is responsible for plagiarism.	Автор самостоятельно подготовил рукопись и несет ответственность за плагиат.
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